Multiple Waveband Temperature Sensor (MWTS)

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Sponsor
Test and Evaluation/Science and Technology (T&E/S&T) Program

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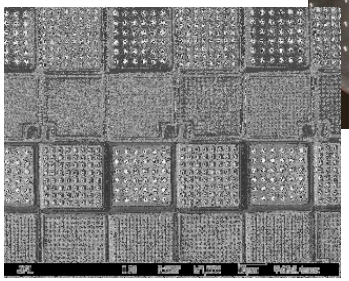
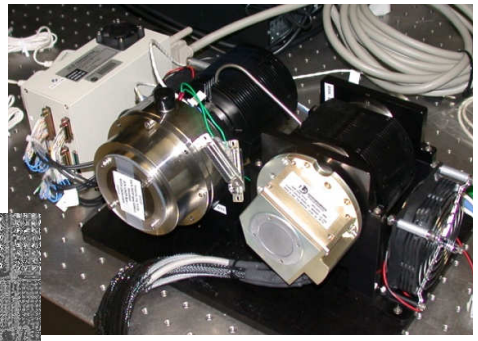
Goals

- **Goal**
  - ***Measure spatially and temporally resolved surface temperature of stationary objects***
- **Specifications to meet the goal**
  - Remote Operation
  - High spatial resolution
  - Temporal resolution 30 frames/sec
  - Calibration temperature range 400 K to 1200 K

S&T Background

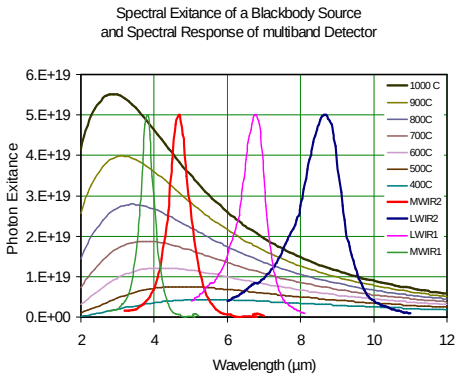
Four-band detector array

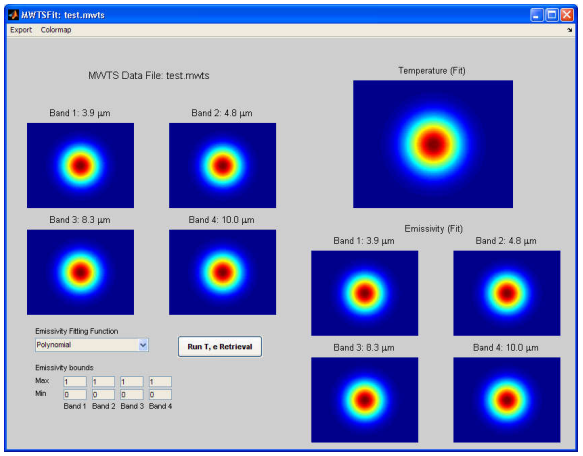




Four band Camera

Four-band IR radiometry

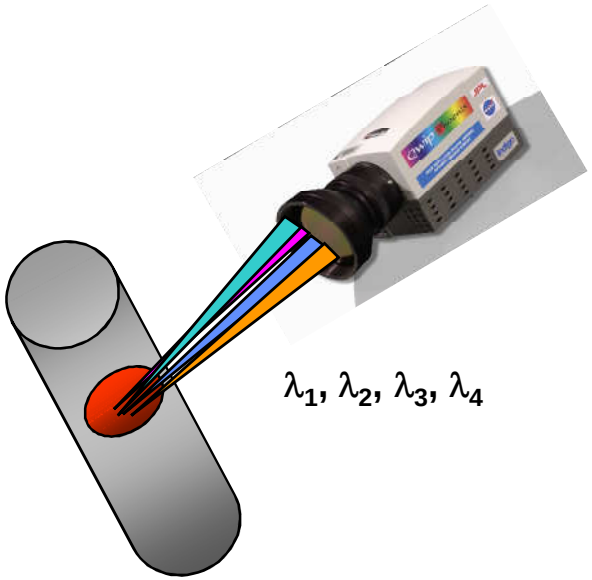


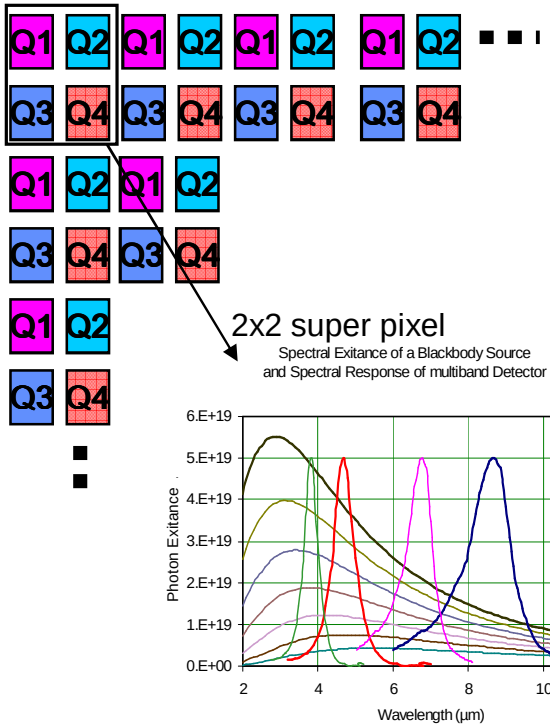


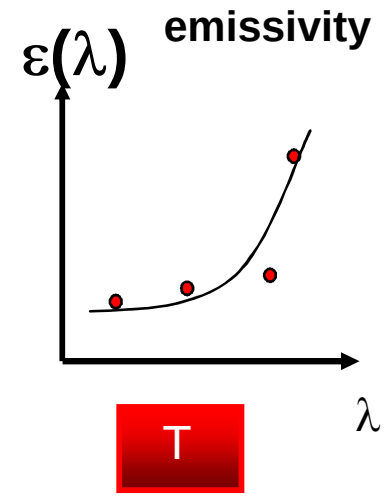
Temperature retrieval software

- **Four-band detector array**
  - Simultaneously sensitive to four distinct infrared bands
- **Four band Camera**
  - Integrate four-band focal plane into a camera
- **Four-band IR radiometric measurement of the object**
  - Calibrate the camera for apparent temperature in four IR bands
  - Image the object in four IR bands
- **Temperature and emissivity retrieval software**
  - 2D images of the onject temperature as a function of time
  - Spectral emissivity of the object

Multiple Waveband Temperature Sensor (MWTS)

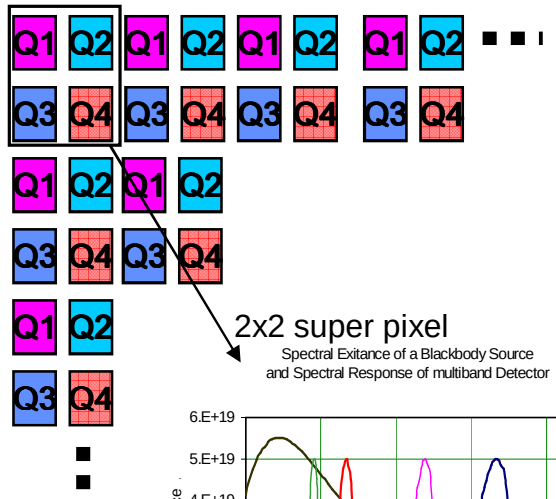


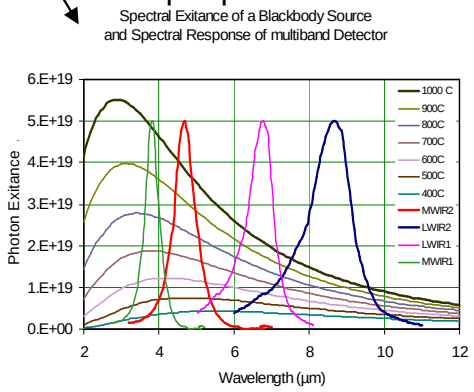


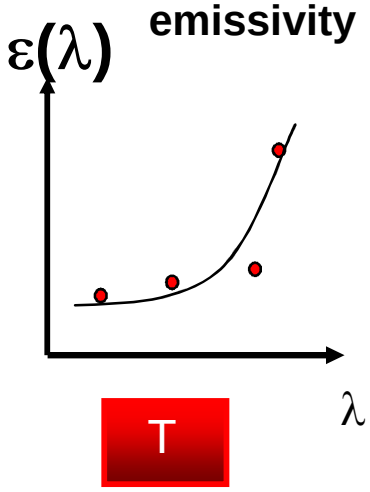


- JPL, in collaboration with WSMR, is developing a four band infrared imaging camera with the detectors simultaneously sensitive to four distinct IR bands.
  - Temperature measurements of external surfaces
  - The measurement system will not affect object dynamics

Temperature Measurement Concept





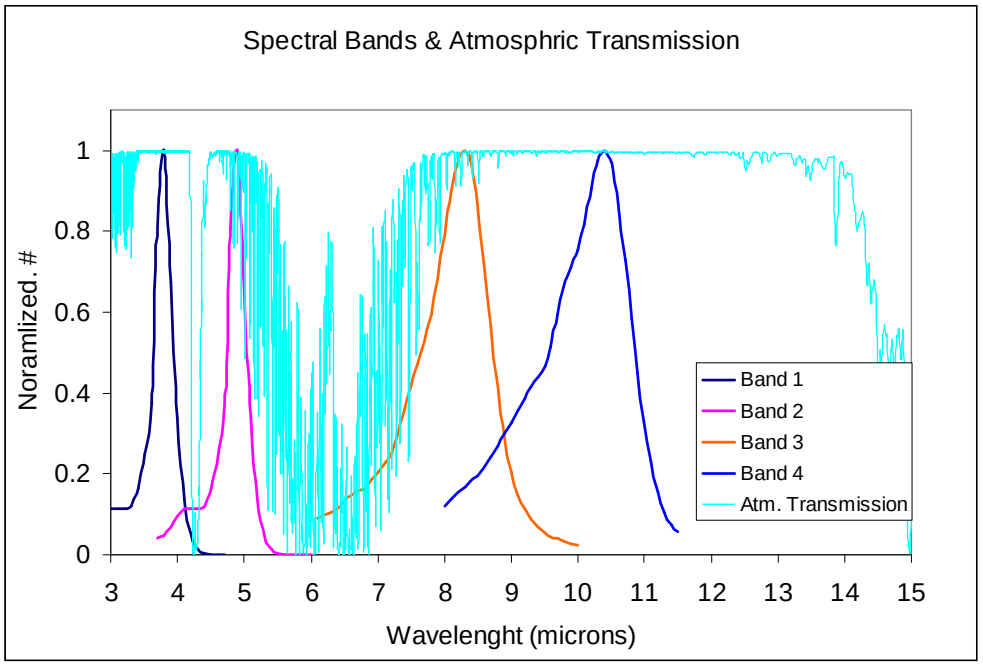


- The FPA area array is divided into 2x2 sub-pixel areas that function as superpixels for temperature measurement
- Each QWIP sub-pixel is sensitive to one specific wavelength band (four) Use multi-point calibration curve to read the apparent black-body temperature of the object in each spectral band
- Use four apparent temperature and (guess) spectral emissivity curve to calculate the actual surface temperature
- Real Time Temperature image display

Multi-Waveband Temperature Measurement Modeling

- **Developed a Matlab program that simulates multiband detection and temperature retrieval**
  - Program Inputs
    - True temperature, T
    - True emissivity, $\varepsilon(\lambda)$
    - Number of spectral bands, and the responsivity of each band
  - Program flow
    1. Simulate the measured detector signal in each spectral band, using the known true temperature and known true emissivity, adding noise if desired
    2. Simulate the detector signal in each band for a guess temperature "T" and spectral emissivity in a functional form
    3. Without any knowledge of the true temperature or emissivity, use the measured signals and the guess signals in conjunction with a search + error minimization algorithm to estimate the temperature and emissivity.

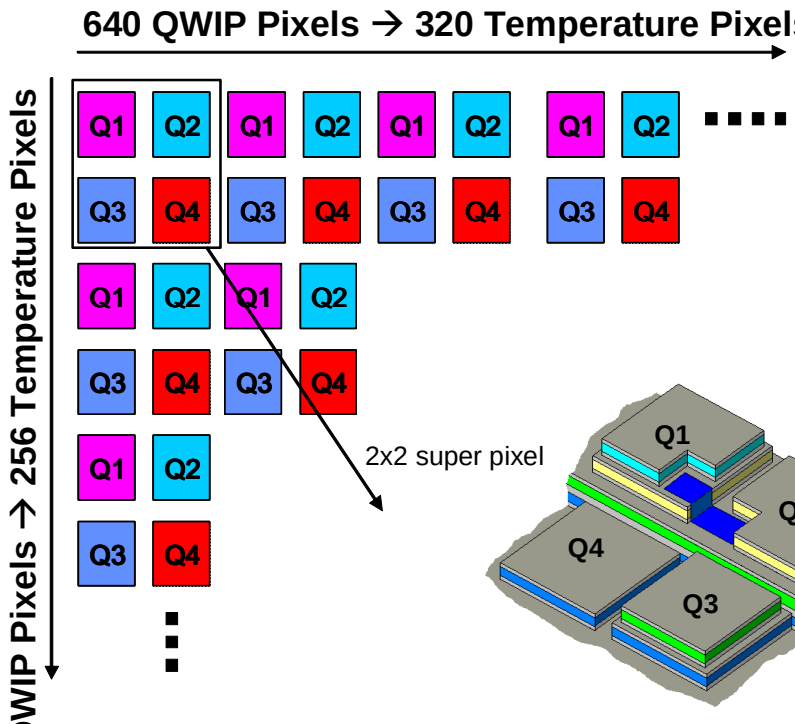
Spectral Band Selection

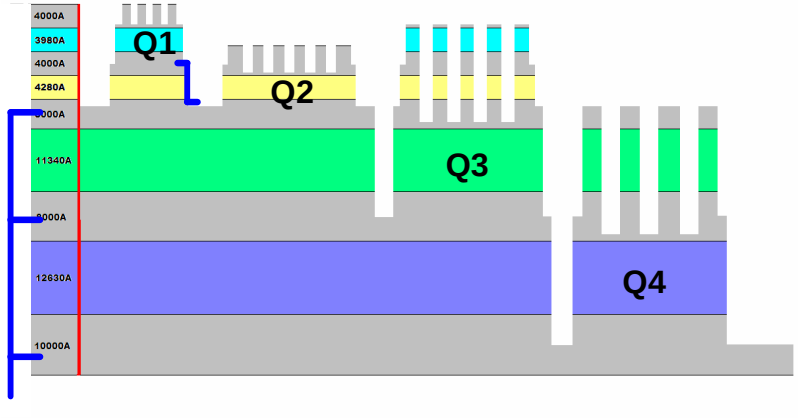


- Need to choose large spreading in spectral bands for the camera to improve the accuracy
- Consider limitations of the detector material
- Avoid atmospheric absorption bands
- Narrow spectral bands to avoid spectral emissivity variation within the band
- Longest band determine the operating temperature of the FPA

Peak wavelength of the selected bands are 3.9 µm, 4.7 µm, ~ 8.0 µm and ~10.0 µm

Four-band FPA Architecture

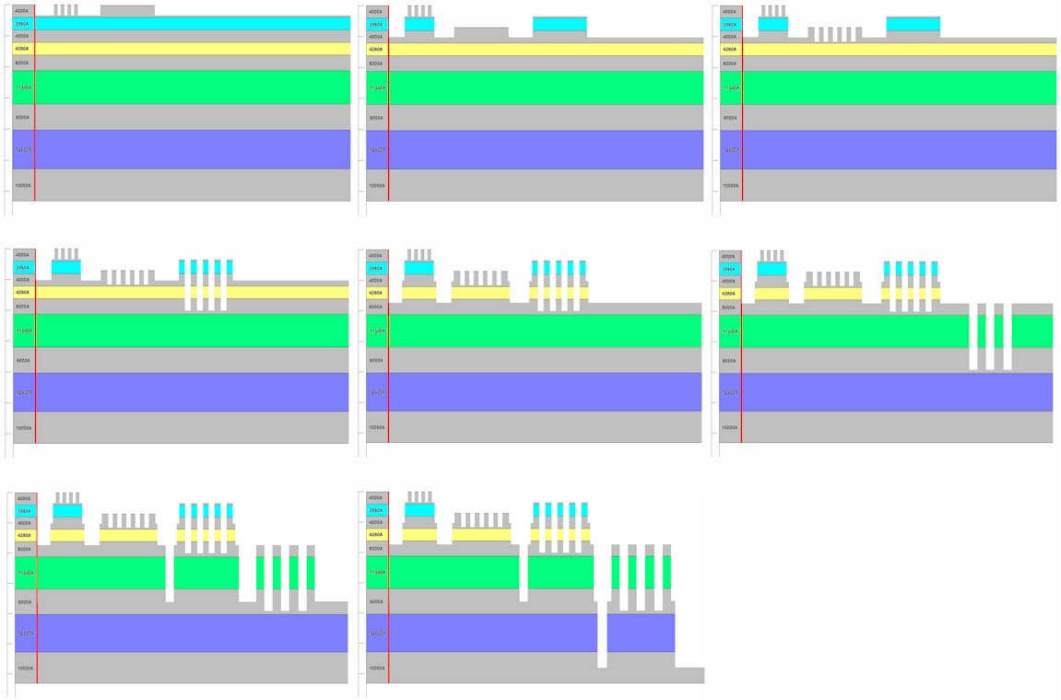




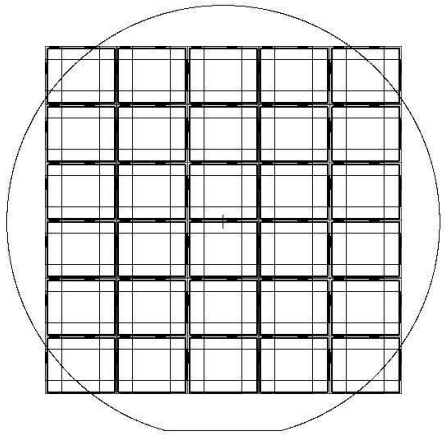
Detector Layer Structure (based on GaAs based quantum well detector technology)

- **Use GaAs based quantum well infrared photodetector (QWIP) stacks tailored to four different spectral bands**
- **The FPA area array is divided into 2x2 sub-pixels**
- **Each sub-pixel is sensitive to one specific wavelength band (four)**
- **Q1 and Q2 bottom contacts are connected at each super-pixel**
- **Q2 and Q3 bottom contacts are unbroken along the rows or columns**
- **Q4 bottom contact is common across the array**

Four-band FPA Fabrication



FPA Fabrication steps after each mask layer

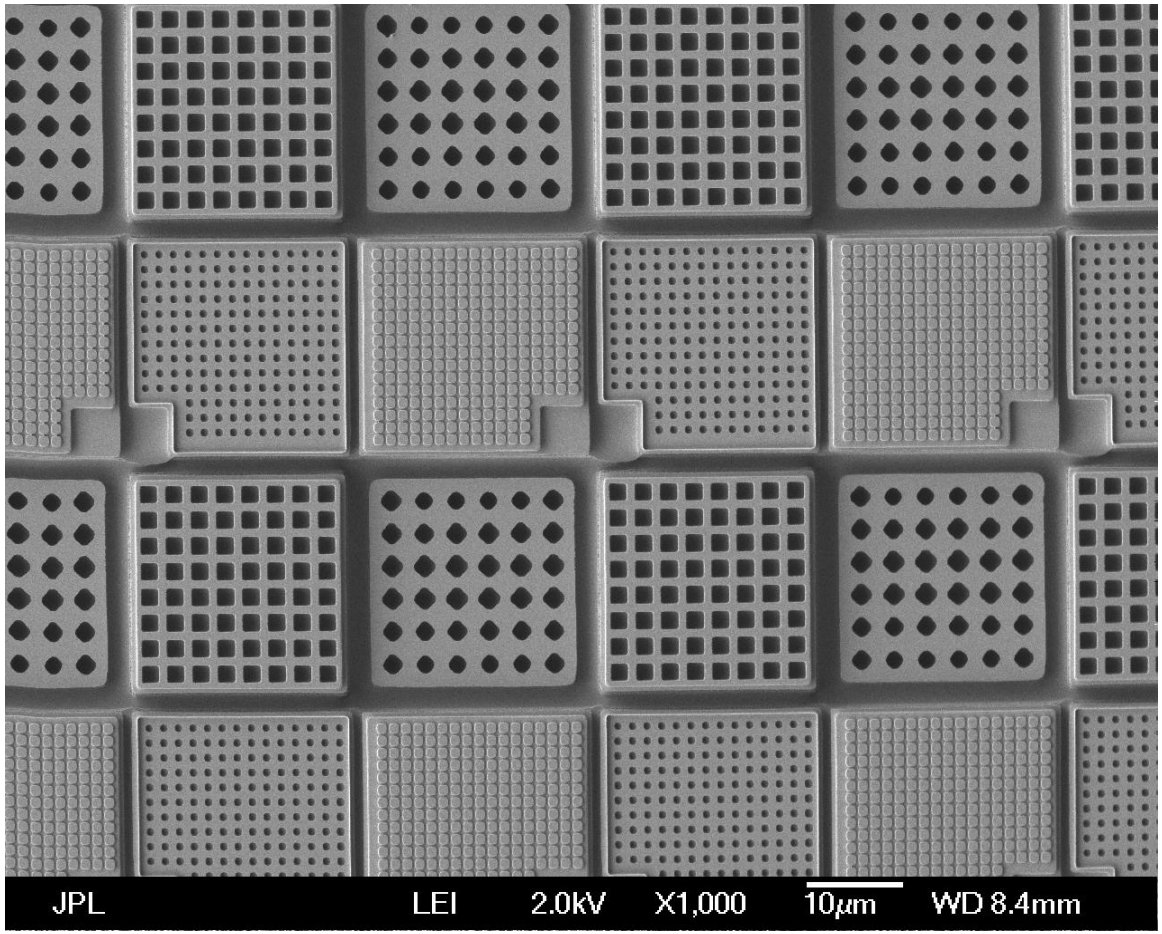


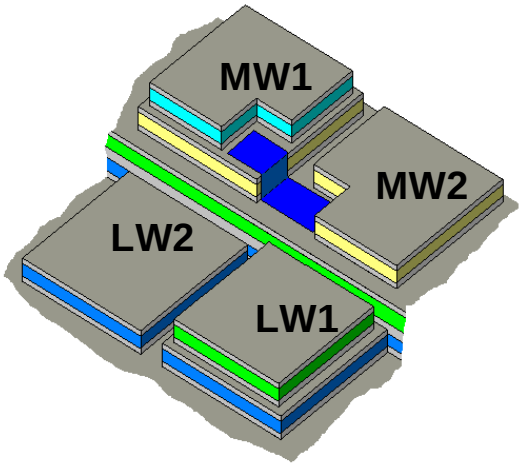
4” Diameter four-band QWIP FPA wafer (Expect 19 good FPAs)

- FPA processing started with 8 wafers
  - **Six GaAs wafers for calibration**
  - **Two actual four-band QWIP wafers**

Technical Detail

Four-band FPA Fabrication

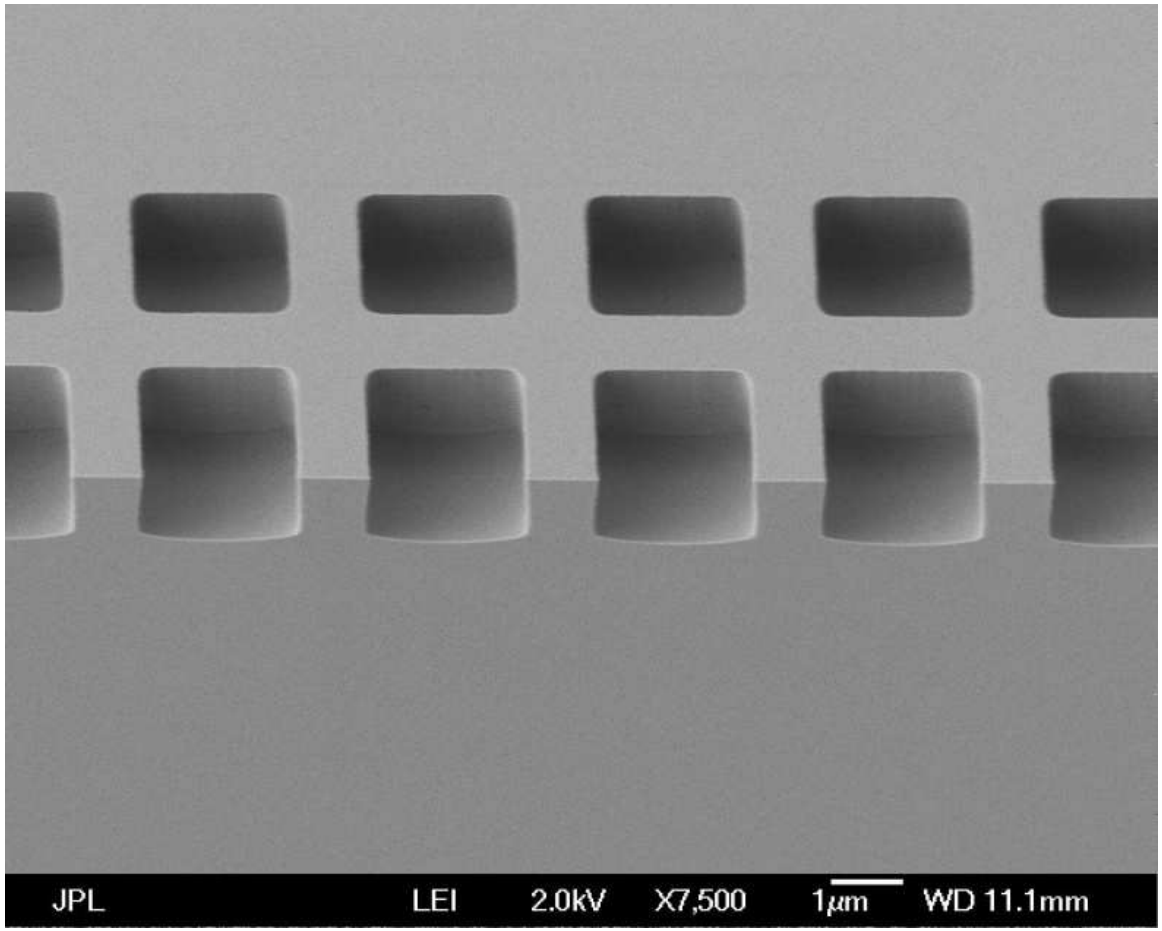




2x2 super pixel Architecture

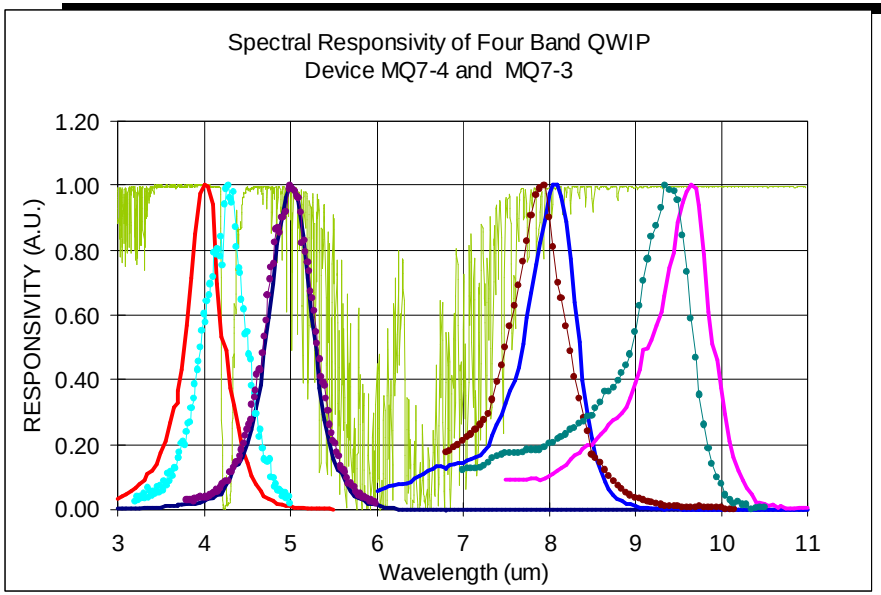
SEM picture of processed four-band array from a GaAs calibration wafer.

Four-band FPA Fabrication: Gratings etch

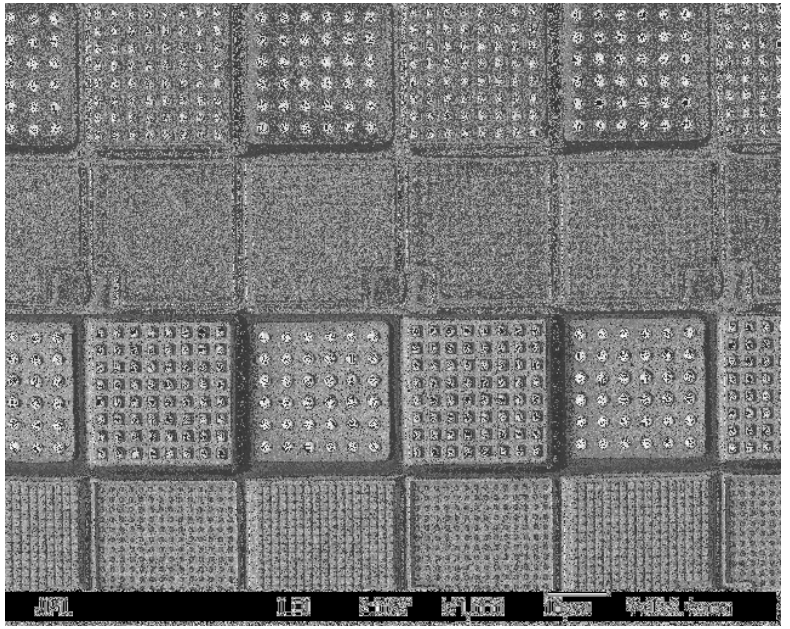


SEM picture of processed grating

FPA Fabrication – In Progress

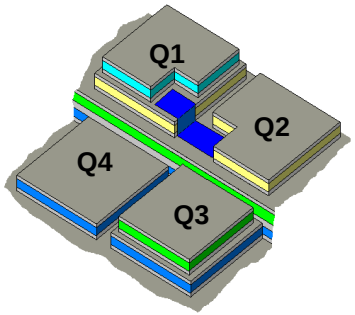


Spectral responsivities of four band QWIP detectors of the FPA material (solid curves) and last test wafer (dotted lines) . The green line indicates atmospheric transmittance for 10m distance at the sea-level.



SEM Pictures of calibration Wafers

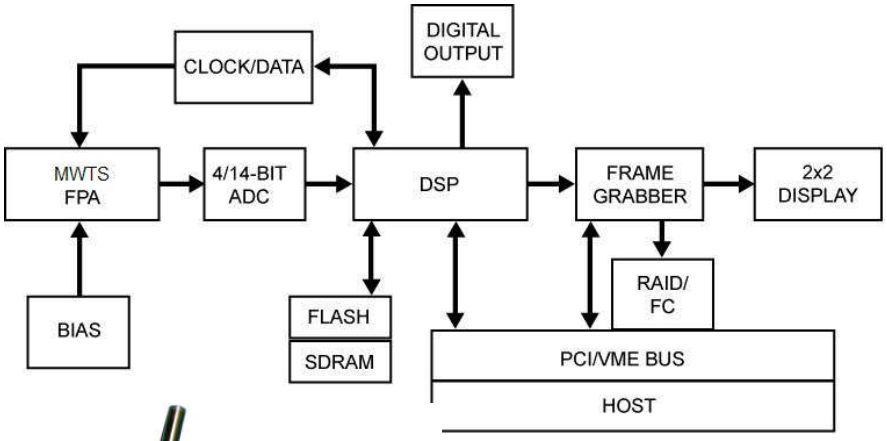
- **Designed and fabricated FPA wafer material (4” wafers)**
- **FPA fabrication is in progress**

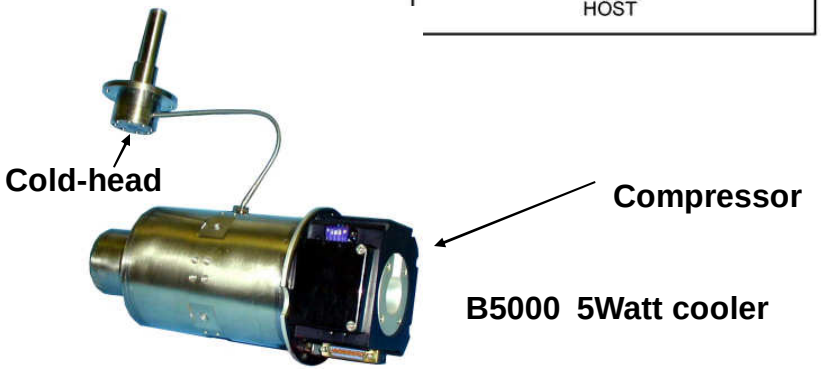


MWTS Pixel Architecture

JPL

Four-band QWIP Camera Design



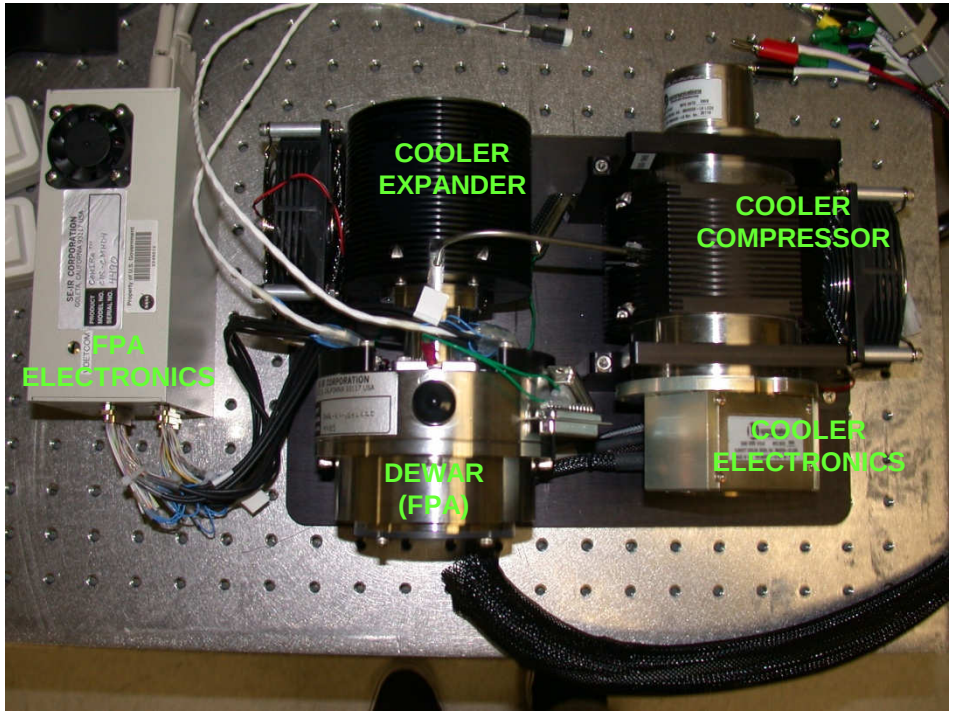


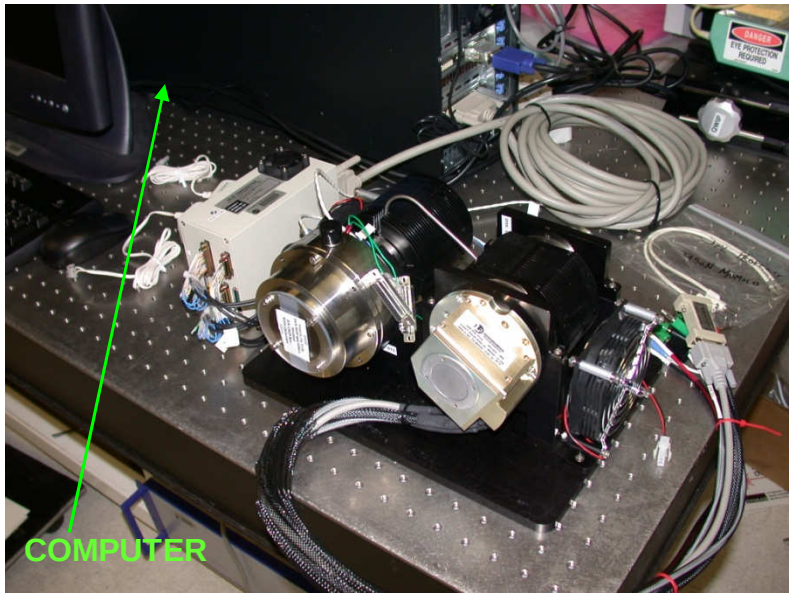
Refrigeration Capacity @ 77K	Up to 5.0 Watts
Cooldown Time (with 1440J Thermal Mass)	<4.0 Minutes
Cooldown Time (with 8000J Thermal Mass)	<14.0 Minutes
Inpt Power	<160 Watts
Voltage, Power Supply	28 VDC
Life, MTTF	>10,000 Hours
Vibration	<0.75 pounds
Weight	<10 Pounds

- FPA read-out integrated chip (ROIC) for the four-band FPA
  - SBF -193 ROIC
  - 640x512 format 24 µm pixel pitch
  - 8.4 million electrons well capacity
  - 120 Hz frame rate with four outputs
  - <55 mW power dissipation
- **CMC Electronics (L3-company) B5000 5W cooler**
  - FPA operating temperature ~ 60K

Technical Detail

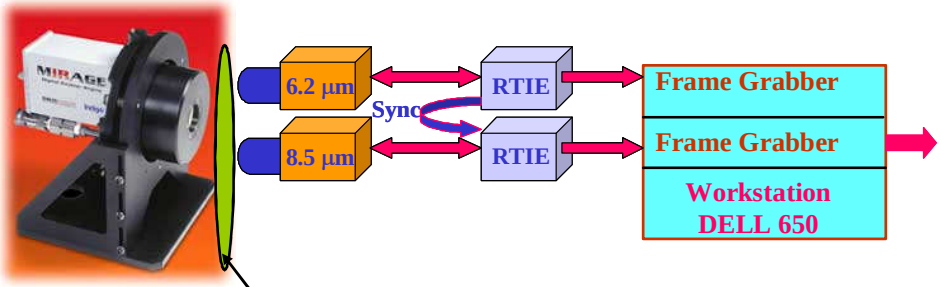
MWTS Camera Hardware

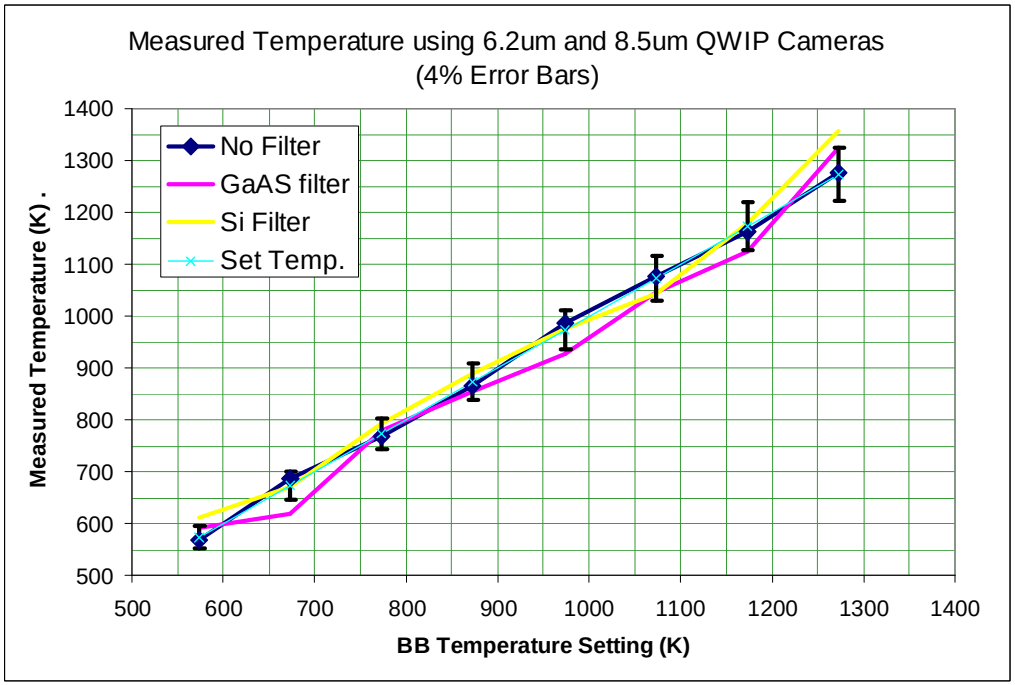




- **Integrated dewar-cooler assembly**
- **Completed cooler and camera operating electronics**
- **Installed Camera operating software**

Temperature Measurements Using Two QWIP Cameras





- GaAs (or Si) wafer is placed in front of the blackbody
- Transmission through wafer to simulate the object with known temperature and unknown emissivity
- Use camera calibration curves (Counts vs flux)
- Use flux ratio to calculate the temperature of the target using new measured counts.
- No spectral emissivity variation
- Most of the measured temperatures are within 4% accuracy.

Wrap-up

- A four-band Infrared Camera is being developed for surface temperature mapping of a target heated by lasers
- Four-band detector array is being fabricated based on GaAs/AlGaAs quantum well layer structure
- Simulate the temperature retrieval techniques using four-band IR camera
  - Some prior knowledge of spectral emissivity is required to obtain the correct temperature! (reasonably good guess for the shape)
  - Typical target materials must be characterized!
  - Smart temperature retrieval processing